Drinking Water Treatment:
Coagulation, Flocculation, and Sedimentation

Subject Area(s) **Environmental Systems, Chemistry**

Associated Unit **Drinking Water Treatment Process**

Lesson Title **Drinking Water Treatment: Coagulation, Flocculation, and Sedimentation**

Header

Image 1

Image file: water_droplet_Lesson2.jpg

ADA Description: A water droplet falls splashes into a pool of water.

Caption: Clean water is necessary but must go through a treatment process before it is safe to drink.

Grade Level 10 (9-12)

Lesson # 2 of 3

Lesson Dependency

Lessons:

1. Introduction into Drinking Water Treatment
2. Drinking Water Treatment: Filtration and Disinfection

Activities:

1. First Steps to Treating Surface Water
2. The Clean-Up Crew: Filtration and Disinfection

Time Required **30**

Summary

In this lesson students learn about the first three steps of a conventional surface water treatment plant: coagulation, flocculation and sedimentation. They learn the basic chemistry behind destabilizing natural water particles and the physics behind encouraging the collision of those particles to form flocs that will settle out of solution. Students acquire knowledge about the specifics of the three processes, while enforcing an understanding of how each process works within the overall design of water treatment.

Engineering Connection

Civil and specifically environmental engineers take water from the environment that is hazardous to human health and treating it so that it is safe to drink. Students will learn and understand the challenges faced by engineers when designing the first three processes of a conventional surface water treatment plant. They will learn to think about not just the science behind engineering, but the practicalities such as cost and feasibility.

Engineering Category = 1

Choose the category that best describes this lesson's amount/depth of engineering content:

1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

Keywords

coagulation, flocculation, sedimentation, water treatment

Educational Standards

National and State

Texas, science, 2009, Environmental Systems 5(B): Identify source, use, quality, management, and conservation of water.

Texas, science, 2009, Chemistry 10(F): Investigate factors that influence solubility's and rates of dissolution such as temperature, agitation, and surface area.

ITEEA Educational Standard(s)

ITEEA, Standard 15, Grades 9-12, M. Conservation is the process of controlling soil erosion, reducing sediment in waterways, conserving water, and improving water quality.

Pre-Requisite Knowledge

Learning Objectives

After this lesson, students should be able to:

- **Describe the science behind the treatment processes coagulation, flocculation and sedimentation.**
- **Explain how the processes of coagulation, flocculation and sedimentation fit into the larger treatment scheme.**

Introduction / Motivation

In the previous lesson we discussed the sources where we collect the water for drinking water treatment, can anyone remind me what the two main sources of fresh water are? (possible student answers: groundwater, surface water, lakes, rivers, ocean). Good, groundwater and surface water are the two main sources where we collect the water that is use for drinking water treatment. Over the next two lessons we will be learning specifically about the treatment processes that are used for treating surface water. The processes that we will be discussing have been developed and optimized by scientists and engineers over many decades, and are used widely throughout the world.

Since we are focusing on surface water, who can remind me of the three main classes of contaminants in water and which of those three we need to focus on the most when considering surface water? (possible student answers: microorganisms, chemicals, parasites). In most cases microorganisms are the main concern when treating surface water because of the ease of fecal contamination from warm blooded animals that live around or in the water source. For this reason, the processes of treating surface water focuses on removing the suspended particles, which include bacteria and other microorganism, from the water.

Lesson Background & Concepts for Teachers

Before diving into the details of the treatment processes, it can be beneficial to discuss the overall philosophy of conventional drinking water treatment. Drinking water treatment plants are unlike most businesses which make products or provide services for consumers, because the production of clean drinking water has a direct impact to the health of the consumers. If the plant is operating properly, no one gets sick from drinking the water, but if the plant does not perform well then people can get sick and even die. The first code of ethics for civil and environmental engineers is to “hold paramount the safety, health, and welfare of the public,” which has implications into the design of drinking water treatment plants. First, while cost is always a constrain of design, drinking water treatment plants are design to be robust and as fool proof as possible. Secondly, drinking water treatment plants are designed with a multi-barrier approach, meaning that there are multiple stages of treatment throughout the entire process that each act as a barrier against contaminants. These different barriers cannot act completely independently of the others to adequately treat the water, but they are designed to be robust enough so that if one of the barriers is not performing well, the other barriers pick up the slack. The first of these barriers is what we are discussing in this lesson, explicitly, the combination of the processes of coagulation, flocculation and sedimentation.

Coagulation

The particles suspended in natural surface water are considered to be thermodynamically stable, meaning that the particles will remained suspended in the water indefinitely if nothing is changed. While there is the possibility of instable particles in natural water, for example a grain of sand suspended in a fast flowing river will settle to the bottom when the current slows down, it is safe to assume that the majority of the particles in the water are stable. The cause of this stability is static electricity. Particles in natural waters are coated with macromolecules called ‘natural organic matter,’ which are produced by the decomposition of organic matter such as leaves, living organisms, aquatic plants, etc. Natural organic matter has functional groups that at neutral pH’s are negatively charged, giving the overall charge of the particles. Because all of the particles are negatively charge, they are repelled by one another so that the particles cannot collide and stick together to form larger and larger particles. Therefore, the goal of the first process in drinking water treatment, coagulation, is to destabilize the particles and allow them the potential to collide and stick together.

There are four main mechanisms for coagulation: double layer compression, adsorption and charge neutralization, sweep flocculation, and inter-particle bridging. Sweep flocculation is the primary mechanism used for drinking water treatment and will be the focus of this lesson. Sweep flocculation occurs with the addition of iron or aluminum, usually added as ferric sulfate or aluminum sulfate, which can easily dissolve into the water. Iron and aluminum form many different cationic species in the pH range of less than 7 or 8, which help destabilize the natural particles by compressing and or eliminating the negative surface charge on the particles. Many other salts and materials can add cations into the water, but what is unique about iron and aluminum is that when they are added at a high enough concentration they will begin to precipitate in the form of iron hydroxide, FeOH(s), and aluminum hydroxide, AlOH(s). It is the formation of these precipitates that instigate the sweep flocculation. The hydroxide solids not only help to eliminate the negative charges on the particles, but form a fluffy and sticky layer around the particles, effectively destabilizing them.

There are two main parameters that control the precipitation of iron and aluminum: the concentration of the iron or aluminum and the pH of the water. The optimum pH at which iron and aluminum are precipitated at the lowest concentration are 6-8 and 6-7 respectively, which is close to the neutral pH range of most natural waters. A complicating factor to the use of iron and aluminum is that they act as an acid and decrease the pH of the water, so to keep the pH in the optimal range it is necessary to add a base material, such as lime. Overall, sustaining the right pH is important so that the most precipitates are formed for a given dose of iron or aluminum.

Although other and potentially cheaper methods of destabilizing the natural particles could be used, adding iron or aluminum to instigate sweep flocculation is the most fool proof and robust method that aids in the effectiveness in the following treatment processes. It is for this reason that engineers design drinking water plants to use sweep flocculation, adding precipitates to the water that hypothetically sweeps the water clean of particles. In actual treatment plants, the addition of iron or aluminum occurs in a rapid mixing basin, where the iron or aluminum are thoroughly mixed into the source water. Water only spends average time of 2-3 minutes in the rapid mix basin before moving onto the flocculation basin.

Flocculation

Once the particles in the water are destabilized through the mechanism of sweep flocculation, they are now able to collide with each other and stick together. Once particles have stuck together they are called a floc, and the process of encouraging the formation of flocs is called flocculation. During the process of flocculation the water is mixed and agitated at a specific rate to encourage the most collisions between the particles as possible. In addition to the mixing, the amount of particles in the water play a role in how well flocs are formed, for if there is very little particle mass in the water, the physical collisions between particles would be difficult to instigate. This is yet another example of why the addition of iron and aluminum is the best choice in coagulation, for the formation of a precipitate helps add to the mass of particles in the water and increases the likelihood of collisions occurring.

There are three main mechanisms that particles can collide and form flocs while in the flocculation basin: Brownian motion (diffusion), fluid shear and differential sedimentation. Brownian motion is the random movement of particles in water due to the continual bombardment of water molecules against the particles. This mechanism causes particles to be continually moving in the water and can lead to collisions between two particles. Fluid shear occurs when there is a velocity gradient in the water due to mixing or the friction of the water against a surface. Collisions can occur between two particles that have different velocities caused by mixing the water. Differential sedimentation is similar to fluid shear, except it is caused by gravity instead of a velocity gradient in the water. In differential sedimentation, collisions occur when large particles or flocs settle at a higher velocity than the smaller particles underneath them. Differential sedimentation can occur in the flocculation basin as well as the sedimentation basin. The size of the particles or already formed flocs has a large role in which one of these collision mechanisms dominates in the flocculation basin; Brownian motion only occurs between two small particles, differential sedimentation only occurs between a large and small particle, but fluid shear collisions can occur between any size particles. For this reason, fluid shear is the primary mechanism of floc formation, making the mechanical mixing of the water important in flocculation.

In the flocculation basin of drinking water treatment plants, paddles are attached to a rotating axil to mechanically mix the water. The rate of mixing should be aggressive enough to optimally cause collision, but not too vigorous as to break up the flocs that have already been formed. For this reason, a common flocculation basin design include two or three different basins in series, starting with a fast mixing rate and ending with a slow mixing rate in the last flocculation basin, so that as the flocs increase in size, the rate of mixing decrease. The average time that water spends in the flocculation basin(s) is 20-30mins, afterwhich the water flows into the sedimentation basin.

Sedimentation

The last process to the first barrier against water contamination is sedimentation. During sedimentation, the flow of the water is slowed to resemble a calm environment. As the water is calmed, the large flocs that have been formed settle to the bottom of the sedimentation basin, sometimes called a clarifier. As the flocs are settling to the bottom, the relatively particle free water passes over a system of weirs and moves to the filtration process.

Sedimentation basins are designed to be rectangles or circles, but in both cases the water is commonly introduced at the bottom of the basin to give the flocs the best chance at completely settling out. A mechanical rack collects the flocs that have reached the bottom and remove them onto what is called sludge treatment. However, not all of the flocs are large enough to settle out and can continue to stay in the water. Stoke’s law describes the velocity at which the flocs settle,

$$v_s = \frac{2}{9}\ \frac{(\rho_f - \rho_L)}{\mu} g R^2$$

where v_s is the settling velocity, ρ_f is the density of the floc, ρ_L is the density of the liquid, μ is the liquids viscosity, g is the force of gravity, and R is the radius of the floc. From Stokes' equation, the two parameters that determine whether or not the flocs successfully settle to the bottom is the floc's density and radius. It is the job of coagulation and flocculation to make the flocs dense and large, but engineers can design the sedimentation basin so that the water spends long enough in the basin to settle out a maximum amount of the flocs formed. Water typically spends a couple of hours in the sedimentation before the top water flows over to be filtered.

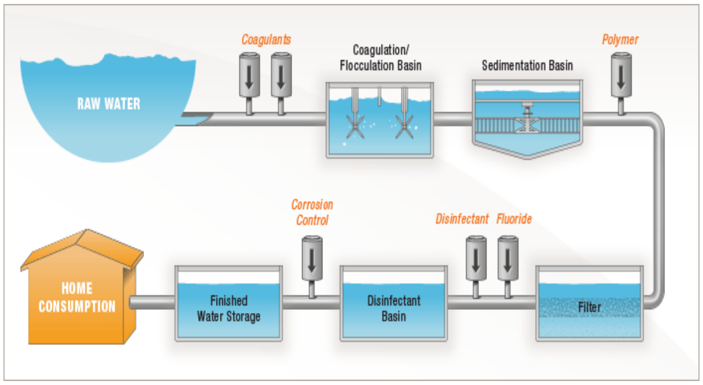

Image 1

Image file: Treatment Process_Lesson2.gif

ADA Description: A simplified graphic representation showing each stage of the drinking water treatment process.

Source/Rights: © Copyright by Denver Water 2013

http://www.water.denver.co.gov/WaterQuality/TreatmentProcess/

Caption: This is the basic process by which water is purified in a treatment facility from start to finish.

Vocabulary / Definitions

Word	Definition
Coagulation	The process of destabilizing the natural water particles so that the inter-particle repulsive forces are minimized
Coagulant	Any material that is used to instigate the coagulation process
Flocculation	The process of encouraging collisions between the destabilized particles to form flocs
Sedimentation	The process of encouraging the settling of flocs out of the water column to the bottom of the basin.
water particle	Any object suspended, not dissolve, in the water column, which includes microorganisms and soil particles.

Associated Activities

First Steps to Treating Surface Water

Lesson Closure

The first three processes of treatment make up the first barrier against contaminants. The main goal of coagulation, flocculation and sedimentation is to remove the particles, which could be harmful to human health, from the water. If done correctly, a majority of the incoming particles formed flocs and settled out in the sedimentation basin, yet there inevitably will be smaller particles or flocs that remain suspended in the water as it leaves. Although the probability of contaminates in the water leaving the sedimentation basin has been greatly reduced, to remove the remaining particles or flocs the water must be first passed through a media filter, which is the second barrier between potential pathogens and the consumer.

Assessment

Summative Assessment: Following the completion of the TeachEngineering Unit: Drinking Water Treatment Processes the students will be given the attached summative assessment, Drinking Water Treatment Quiz.

Lesson Extension Activities

Additional Multimedia Support

References

Attachments

Lesson2_guided_notes_and_Activity1.docx

Other

Redirect URL

Contributors

Brad Beless and Jeremy Ardner

Supporting Program

University of Houston, National Science Foundation GK-12 and Research Experience for Teachers (RET) Programs

Acknowledgements